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AN EXPERIMENTAL STUDY OF A TURBULENT BOUNDARY LAYER  
IN THE TRAILING EDGE REGION  
OF A CIRCULATION-CONTROL AIRFOIL

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## ABSTRACT

This report discusses progress made on NASA Cooperative Agreement NCC 2-545, "An Experimental Study of a Turbulent Boundary Layer in the Trailing-Edge Region of a Circulation-Control Airfoil," during the period 9/1/91 through 9/30/92. The study, being conducted by Jeff Brown of the Elore Institute, in conjunction with the Experimental Fluid Dynamics Branch at NASA Ames (John Viegas, technical monitor), features 2-component laser Doppler velocimeter (LDV) measurements in the trailing edge and wake regions of a generic 2-dimensional circulation-control model. The final experimental phase of the study will be carried out in the Ames High Reynolds Number Channel II (HRC2) transonic blow-down facility. During the 13-month period covered by this report, work continued on the development of the near-wall laser Doppler velocimeter (LDV) described in previous reports.

## INTRODUCTION

Circulation control refers to the augmentation of lift on an airfoil through the tangential blowing of a high-velocity air jet over a smooth, tightly-curved leading and/or trailing edge. The tendency for such a jet to remain attached to the curved surface, known as the Coanda effect, while entraining much of the boundary layer passing over the airfoil, greatly delays trailing-edge separation and enhances lift beyond the capacity of conventional flaps. The technology could be applied to aircraft on which low take-off and landing speeds are imposed. It could also provide quick-response lift adjustments in wind-shear situations.

Circulation control (CC) technology, in general, also involves the kind of complex flow conditions that most greatly challenge those trying to (computationally) predict turbulent flow behavior. In past years, various attempts have been made to compute the flow around generic cc airfoils, but success has been limited. One significant need seems to

be a turbulence model that can perform reliably for a boundary layer subjected to the combined effects of compressibility, mass injection, strong streamwise curvature, and separation: all of which are endemic to the trailing edge flow over a CC airfoil. Presently there is a distinct lack of the experimental data that are needed to guide the development of such a model.

NASA Cooperative Agreement NCC 2-545 supports an experiment designed to provide such data. Final testing will be conducted in the High Reynolds Number Channel II (HRC2) facility at Ames, a transonic blow-down wind tunnel that allows for Mach and Reynolds numbers within the range of practical application for CC airfoils. The HRC2 has a dedicated 2-component laser Doppler velocimeter (LDV) and an electronic instrumentation patch board that links directly to a Micro-Vax computer. The Micro-Vax is connected to the Ames computer network, so data stored on it will be directly accessible to computationalists.

#### PREVIOUS WORK

Between 1988 and 1990, project work concentrated on three areas: 1) the design and fabrication of the CC-airfoil flow model, 2) the design and fabrication of a high-pressure auxiliary air delivery system, and 3) the installation of a computer-controlled, high-accuracy, 2-component laser traversing system. These tasks were described in detail in previous reports.

The airfoil model has a 23 inch chord and a 16 inch span. The leading edge is a NACA 0012 design, and the trailing edge is circular with a 1 inch radius.

The air system, to pressurize the model's internal plenum and generate LDV seed in the tunnel stagnation chamber, is designed to provide up to one pound of air per second at 75 psi to the model and one pound per second at 450 psi to the tunnel plenum.

## NEAR-WALL LDV

The prime motivator for the overall project is the need to develop accurate reliable turbulence models for complex flows. Near-wall data (i.e., those extending into the viscous sublayer) are essential to this pursuit. Yet there are fundamental difficulties in obtaining these data with LDV due to the high component of noise typically generated by diffuse surface light scattering. Meanwhile, hot-wire anemometry, the only plausible alternative for obtaining turbulence measurements, is unsuitable for separating/recirculating flows: the kinds of flows encountered in circulation-control applications, and for which turbulence models are most needed.

Since December 1989, Jeff Brown has collaborated with Dennis Johnson (of NASA Ames) to develop and refine a new near-wall LDV technique proposed by the latter. Ultimately, the technique would be used to make near-wall turbulence measurements in the High Reynolds II facility.

The initial phase of the collaboration concentrated on demonstrating the technique for single-component measurements in a 2D boundary layer; it was documented in reference 1. In June 1990, the LDV system was transported to a 3-dimensional boundary layer facility, on loan to NASA from Stanford University. The goal in the 3D wind tunnel is to make accurate, reliable measurements of the full Reynolds stress tensor in a 3D boundary layer, particularly near the solid surface.

## RECENT WORK

Past (i.e., prior to this report cycle) refinements made to the near-wall LDV were directed toward enhancing beam coincidence and reducing the effects of "apparent turbulence" due to beam orientation and fringe divergence. The specific steps taken were described in previous reports. In the past 13 months a major modification was made to the LDV that makes it both more compact and more portable. The technique and

material used to seed the flow were also changed to provide higher data rates and protect the integrity of optical surfaces. Preliminary three-dimensional data were acquired. Finally, conceptual work was begun on adapting the near-wall LDV technique to the HRC2 facility and on developing a near-wall system that measures all three velocity components simultaneously.

One very essential capability of the near-wall LDV is that it creates a very small measurement volume, approximately 40 microns in diameter. Previously, the system used a total optical path length (from the back mirror of the laser to the final focusing lens) of about 5.5 meters to do this. Obtaining such a large path length in a small area required reflecting the beams off several mirrors, each with their own associated energy losses and possible misalignments. System lenses (a telescoping lens and the final focusing lens) and the Bragg Cell were positioned so that, at the beginning of a measurement traverse, the beam-crossing location coincided with the individual beam waists. And, the collecting optics were positioned to view that location. During a traverse, however, the final lens moved (over the traverse distance) relative to the stationary Bragg Cell and telescoping lens. This caused the beam crossing to move relative to the beam waist, and both to move away from the collecting optics' viewing location, thus resulting in non-parallel fringes and the need to periodically realign the collecting optics during full boundary layer traverses. In March 1992, the system configuration was modified significantly so that the relative positions of the lenses and Bragg Cell (as well as the total optical path length) remain constant during a traverse of any length, thereby eliminating the aforementioned problems. The laser beam now passes directly from the laser into a 3-micron fiber optic cable which attaches directly to the 2D Bragg Cell. The Bragg Cell is mounted to a metal tube (approximately 3 cm in diameter and 30 cm long) that contains the necessary mirrors and

lenses to create the same 40 micron probe volume as the original system. Roughly 5 meters of individually mounted optics has been condensed into a single tube (a little bigger than a foot-long hot dog) attached to a light, flexible cable. It is highly compact, and, by virtue of the optics all being fixed on or inside the tube, and the laser beam passing to the tube through a fiber cable, the tube (and thus the measurement volume) can be repositioned and reoriented almost trivially. This quality is vital in the effort to make 3-dimensional measurements while measuring only two velocity components simultaneously.

Data rates and seed-particle generation are two other important considerations to this (and any other) LDV technique. In the earlier stages of work on the near-wall LDV, data rates were consistently too low to obtain, in a reasonable time, the required number of data to give statistically reliable results. This was especially true in the region nearest the wall. At the time, seed particles were generated by aerating silicon oil through a sprayer nozzle located upstream of the tunnel blower inlet. The sprayer nozzle was subsequently moved to a sidewall port, just downstream of the blower and settling screens. This resulted in much higher data rates, particularly near the wall. However, the side-wall (sprayer) jet, although close to one hundred boundary layer thicknesses upstream of the test section, appeared to raise the free-stream turbulence level of the flow. The oil also deposited on windows and the mirror probe, distorting the beams. Most recently, seeding has been achieved with a sonic resonating nozzle positioned between the tunnel blower and the settling screens, along the tunnel axis. Water was the seed material used. While the quality of the doppler signals generated with the water is very good, and the free stream turbulence levels are very low, data rates are also low due to evaporation of much of the seed before reaching the test section. Work in the immediate future will concentrate on identifying a non-toxic, water-soluble seed material that will not evaporate

as quickly as water.

Preliminary measurements were made in the 3D boundary layer. In order to ascertain all Reynolds stress components with the 2-component system, it was necessary to take data at three different measurement orientations. These data are currently being reduced.

Finally, conceptual work has begun on adapting the near-wall LDV technique for experimentation in the High Reynolds Channel II facility, and on developing a system capable of measuring all three velocity components simultaneously.

#### CONCLUSION

Work under NASA Cooperative Agreement NCC 2-545 during the period between 9/1/91 and 9/30/92 has focused on the continued development of the near-wall LDV measurement technique that shows great promise for application to the HRC2 circulation-control experiment: one that could provide extremely valuable turbulence data.

Work in the immediate future under this agreement will remain focused on the LDV technique: in particular, in raising the data rate with an appropriate seed material, and on accurately measuring the full Reynolds stress tensor.

#### REFERENCES

- 1 Johnson, D.A. and Brown, J.D., "An LDV Approach for Near Wall Turbulence Measurements," presented at The Fifth International Symposium on Applications of Laser Techniques in Fluid Mechanics, Lisbon, Portugal, July 1990.